Analysis of Posterior Zirconia Crowns with Vertical Margin Preparations

ABSTRACT

Background: The interest in vertical crown preparation is growing and several variations are presented in the dental literature but limited clinical outcome data exists for teeth prepared for a vertical finish line. Aim: To audit clinical outcomes for 73 teeth after vertical preparation for knife-edge zirconia crowns. Method: Seventy-three teeth had knife-edge zirconia crowns placed after vertical finish line preparation. The outcomes for these teeth were analysed from a retrospective audit of clinical records. Results: The mean follow-up time was 21 months (SD: 10 months; range: 6-40). One tooth had to be extracted due to fracture at cervical level. One crown had to be re-made after margin fracture during try-in. No subsequent endodontic treatment was needed for any of the prepared teeth. No change in alveolar bone height was noted on radiographic follow-up. The mean bleeding score for the crowned teeth was higher than the mean bleeding score for a control tooth, but this was not statistically significant. Conclusion: This retrospective evaluation has shown favourable outcomes for 72 teeth after vertical preparation for knife-edge crowns. Longer follow-up is needed but the present results show that the technique is a viable procedure with potential advantages.

INTRODUCTION

Crowns are often used to restore the function and appearance of broken-down teeth.[1] While the application of adhesive dentistry has meant that crowns are prescribed less frequently, a crown is still indicated when replacing a failing crown or when restoring a heavily broken-down tooth. The most recent Adult Dental Health Survey (2009) shows that the 37% of adults in the United Kingdom have at least one crown.[2] This rises to 59% in patients over 45. Of the adults with crowns, each had an average of three crowns. The most common reasons for replacement of an existing crown are aesthetics (21%), recurrent caries (20%), lost crown (15%) and crown fracture (15%).[3] When replacing a crown, it may be necessary to prepare the new finish line more apically than the previous finish line. Full-coverage crowns may be prescribed less often as newer adhesive techniques grow in popularity. Nevertheless, it is essential to provide modern, minimally invasive crown preparations in those cases where crowns are necessary.

Pardo[4] classified finish lines as horizontal or vertical. A horizontal preparation has a defined finish line which allows space for the restorative material and communicates to the laboratory technician the precise location of the desired crown margin. A vertical preparation does not have a defined finish line. Horizontal preparations include those prepared with a shoulder or chamfer margin, while vertical preparations include those prepared with a knife edge, featheredge or shoulderless approach.[4,5]

Keywords

Crowns
Indirect Restorations
Vertical Margins

Authors

Jane Stack *
(BDS, MSc (Fixed & Removable Prosthodontics))

Brian J. Millar *
(BDS, PhD, FDSRCS, FHEA, FDT, FFGDP, FCGDent)

Address for Correspondence

Brian J. Millar *

Email: brian.millar@kcl.ac.uk

* *Kings College London, Restorative Dentistry, Denmark Hill, London SE5 9RW*

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Horizontal margins *(Table 1)* are indicated when there is good periodontal health, when the clinical and anatomic crown coincide.[6] The crown margin is placed near the cemento-enamel junction (CEJ). If the crown margin needs to be below the CEJ, a vertical margin *(Table 2)* should be considered.

Table 1. Horizontal finish lines - advantages and disadvantages

Horizontal Finish Lines[5]

Advantages	Disadvantages
Easier to judge the degree of axial reduction during preparation	A greater degree of gingival retraction is required since the impression material must capture the root surface beyond the finish line
Finish line is clearly visible	Marginal fit/closure is less accurate
Any subgingival preparation is clearly defined	Open margins cannot be corrected chair-side
The emergence profile can follow the root contour (meaning no horizontal or vertical overcontour)	Ferrule effect is created at the expense of tooth structure, especially cervical dentine

Table 2. Vertical finish lines - advantages and disadvantages

Vertical Finish Lines[5]

Advantages	Disadvantages
Less axial tooth reduction	More difficult to judge axial reduction of abutment
Simpler gingival retraction and impression taking in some cases	More difficult to visualise subgingival preparation
Simpler marginal closure with provisional prosthesis	The technician defines the depth of margin within the sulcus, rather than the clinician
Better marginal closure with definitive restoration	It is not possible for the emergence profile to follow the root contour
Open margins can be corrected chair-side	

One of the most common indications for vertical margins is the preparation of periodontally involved teeth. In these cases, horizontal margin preparation may necessitate excessive root surface reduction and compromise the long-term prognosis of the tooth. Di Febo[7] illustrates the use different margins including feathered margins, chamfers and shoulders in the "Combined Preparation Technique" at the level of the bony crest in order to even out concavities associated with root furcations and went on to publish successful 20-year follow up reports.[8] Applying the vertical preparation technique to periodontally healthy patients was pioneered in the 1990s by Bruna.[5]

Knife-edge and featheredge margins require a material that is very strong and resistant to fracture in thin section. This has been possible for decades with metal margins. Preparations for full gold crowns have long been acknowledged as the most conservative. Porcelain fused to metal crown with a metal-only collar is suitable for vertical margin closure in non-visible areas. Zirconia is biocompatible and can be fabricated with a knife-edge margin, bridging the gap between aesthetic requirements and conservation of tooth structure with a vertical preparation.

Marginal adaptation for vertical preparations is better than for horizontal preparations, shown both *in-vitro* and determined mathematically.[9,10] As the marginal angle reduces, the marginal gap approaches zero, and so a vertical preparation gets as close to zero as possible. A tapered fit design can have a wedging effect at the vertical finishing area, which could lead to incomplete seating. This can be overcome by creating a cement space. The die is coated with spacer varnish but the finishing area is left uncovered. This avoids premature contacts and allows close marginal adaptation to occur at the finishing area.

When considering vertical margin closure, the emergence of the final restoration mimics the natural emergence profile of enamel. Traditional thinking suggests that a vertical preparation leads to a crown margin overhang with resultant inflammation. The presence of an overhang should be considered as distinct from a correctly executed emergence profile.[5] Tissue handling and margin form (created by a skilled technician) are critical to success.

The use of the vertical preparation techniques has been described in several ways. The Biologically Oriented Preparation Technique (BOPT) is the most widely known of the vertical preparation techniques.[6,11] BOPT allows for moving the crown margin in an apical direction when needed including the elimination of existing finish lines in previously prepared teeth. The aim is to create a new crown with an emergence profile that simulates the emergence of the natural tooth.[12] There is a controlled invasion of the gingival sulcus (0.5-1mm, depending on sulcus depth and supracrestal tissue attachment). During preparation, there is light gingittage of the internal wall of the sulcus and this heals during a 4-8 week period where a lab-made provisional crown is in place. The position and emergence profile of the new prosthetic CEJ allows the gingiva to thicken and adapt, improving the gingival margin aesthetics and health. The Shoulderless Approach[13] proposes an alternative with placement of the final restoration as soon as possible so that soft tissue regeneration is guided by the contours of the definitive restoration. Violation of the supracrestal tissue attachment is avoided by using a non-working tip bur. Other variations include the Featheredge Preparation[14] and Vertical Margin Closure.[5] Table 3 shows the main differences between the vertical preparation techniques described.

It is essential to work with a dental technician who is skilled in vertical preparation techniques, as they will decide on the exact finish line placement. At the laboratory, the technician marks the gingival level on the model. The model gingival tissue is removed, and the subgingival apical extent of the preparation is marked with another line. The area between these lines is the 'finishing area' and the technician will place the

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Table 3. Comparison of variations of vertical preparation

	Magallanes Ramos *et al*[13]	Scutella *et al*[14]	BOPT[6,11]	Bruna *et al*[5]
Depth of preparation subgingivally	Limited by sulcus depth as bur has non-cutting end and cannot prepare deepest millimetre of sulcus	1mm	Entire depth of gingival sulcus and 0.3mm epithelial tissue	Intrasulcular preparation is almost to maximal probing depths
Type of bur used for subgingival preparation	Batt-bur with non-working tip	Komet 6862D/012; laser-marked dot at 1mm to control depth of preparation	Conical diamond bur (1.2mm diameter; 100/200 particle size)	Flame shaped bur, markings of millimetre depth praised as useful for control of sulcus penetration
Time before impression	Immediate	1-2 weeks; conventional silicone or digital intraoral scanning	8 week[11] 4 weeks[6] 2-step elastomer impression with double retraction cord	At least 40 days
Definitive crown material	Zirconia	Metal-ceramic, zirconium oxide or lithium disilicate depending on case requirements	Zirconia used, metal ceramic and lithium disilicate suggested as alternatives[11]	Metal ceramic, zirconia suggested as promising
Emergence angle of provisional crown	Not specified	Not specified	45°	45°

crown margin within this area. The finishing line position is based on sulcus depth and desired aesthetic outcome. The technician will create an ideal contour and profile with the margin emerging at 45° and the restoration will be polished to a crisp, knife-edge.

There is a lack of clinical studies reporting on the above techniques which are all a variation of the vertical margin concept. The aim of this audit was to evaluate the clinical outcomes for 73 teeth prepared with a vertical finish line preparation and restored with a zirconia knife-edge crown, placed in general practice.

METHODS

The data collection was carried out in 2019 by analysing patient records in a private practice in England. All patients treated for one or more posterior single crowns over a three-year period (2016-2018) were identified. Only patients who were treated with a vertical preparation and had follow-up data were included in this audit. This follow-up data was recorded during routine examination and hygiene appointments.

Seventy-three knife-edge zirconia crowns were included. These preparations were carried out by two separate clinicians following the same protocol. The follow-up data was recorded by one of these clinicians and a hygienist, as part of ongoing care. Crown survival, marginal integrity, endodontic health and periodontal health were of interest to the audit.

At the time of treatment, each individual tooth received a vertical shoulderless preparation, including an occlusal reduction of approximately 2mm. The vertical finish line was created with a non-working tip bur (Komet 857 314/014, *Figure 1*). This bur has a taper of about 2° and an apical diameter of only 0.7mm to allow a conservative preparation. It has a non-cutting end of 1mm which allows intrasulcular preparation and light gingittage without violating the supracrestal tissue attachment. The margin preparation was guided by the tooth anatomy and the depth of the sulcus. A fine-grit diamond bur was then used to refine the preparation to ensure a smooth preparation surface. Most cases had the impression taken at the preparation appointment. A double retraction cord technique was used to retract the soft tissues (Ultrapack; Ultradent Products Inc, South Jordan, Utah). Preparations and opposing arches were scanned with an intra-oral digital scanner (TRIOS; 3shape, Copenhagen) to create a digital model. In some cases, a dual-phase addition cured silicone impression was made in a rigid metal stock tray. The heavy body silicone was automixed and the light body silicone was syringed onto the preparation for maximum accuracy. A provisional crown was made chair-side from a bisacryl composite (Luxatemp; DMG, Germany) using a pre-operative putty matrix. The provisional crown margin was adapted with a flowable composite to ensure marginal integrity and adequate emergence profile. This provisional was luted with zinc oxide eugenol (ZOE) cement (Temp Bond; Kerr Corporation, Orange, California).

Figure 1: Komet 857 314/014 bur, showing the non-cutting tip which ensures the base of the sulcus is not violated

At the laboratory, a zirconia knife-edge margin framework was fabricated using a CAD-CAM procedure. Some crowns were entirely monolithic zirconia, whilst those in a more visible position were veneered with porcelain to improve aesthetics. The crowns were designed with an emergence profile which mimics the natural emergence profile of enamel on natural teeth. The finish line position was decided by an experienced laboratory technician based on the 'finishing area' between the gingival margin and the apical extent of the preparation.

After approximately two weeks, the crown in question was tried in and cemented (Rely-X Unicem or Ketac Cem, both 3M ESPE, Seefeld, Germany). Soft tissue healing took place around the definitive crown in almost all cases. A handful of cases had provisional crowns for longer periods, depending on the individual clinical circumstances. An example of a case is illustrated in Figures 2-14.

Patients re-attended for examination and hygiene appointments based on their individual risk profile, which was most commonly every 6 months. BPE scores were recorded at each visit and periodontal pocketing was recorded for any patients who recorded a BPE score of 3 or 4. Bleeding charts were recorded when needed. Bleeding charts were available for 68 of the teeth in the audit. The data was calculated as number of surfaces with bleeding on probing. If there was bleeding on mesial and palatal surfaces, this was counted as 2 surfaces. If there was more than one bleeding record available, an average was calculated.

Bite-wing radiographs were taken for patients to aid caries diagnosis, at an interval appropriate to their caries risk profile. Crowns were visually evaluated at each examination for any chips, cracks or marginal gaps.

A control tooth was also chosen for comparison. This was another crowned tooth in the mouth. Contralateral teeth were first choice, followed by opposing or adjacent crowns. Where no other crowns were available, a heavily filled contralateral tooth was chosen. For the following comparisons, teeth prepared for a vertical preparation crown will be referred to as 'crowned teeth' whilst the control teeth chosen for comparison will be referred to as 'control teeth'.

Figure 2: Pre-op peri-apical radiograph of 16 and 17, both are heavily filled and root treated and require full-coverage crowns

Figure 3: Vertical preparation of 17 and 16, double retraction cord in place ahead of impression

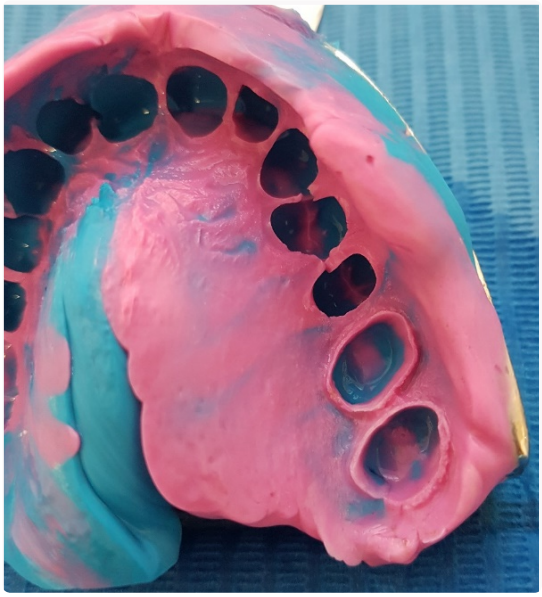

Figure 4: Impression of preparations using dual-phase addition silicone in a rigid custom tray

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Figure 5: 16 and 17 dies, after ditching of the margin

Figure 6: 16 and 17 model with definitive crowns

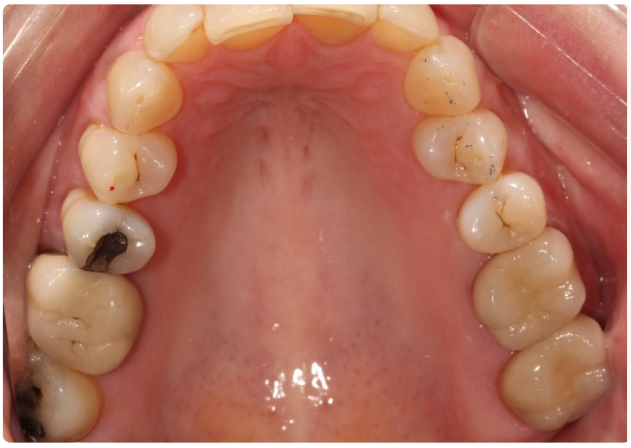

Figure 7: Crowns fitted 16 and 17

Figure 8: Buccal view of 16 and 17 fitted crowns

Figure 9: 6 months after completion of treatment of the upper right, the 36 developed irreversible pulpitis due to a distal crack and needed endodontic treatment

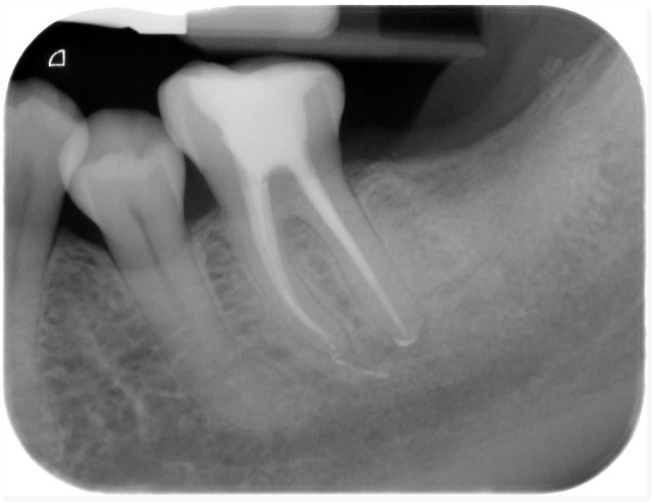

Figure 10: 36 root treatment complete

Figure 11: 36 prepared with vertical preparation

Figure 12: Close-up of 36 preparation on TRIOS digital optical impression

Figure 13: TRIOS optical impression showing both arches

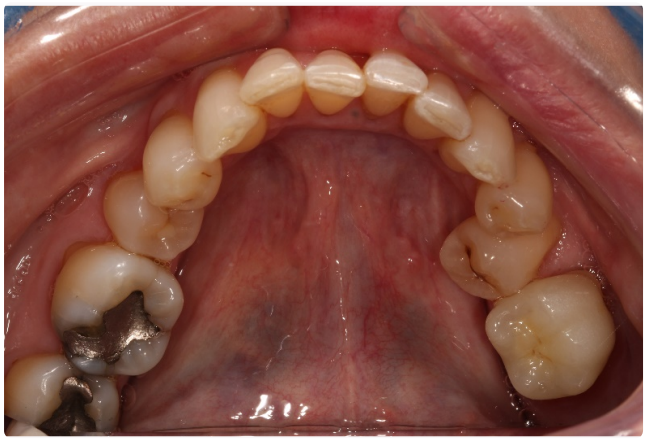

Figure 14: 36 crown fitted

RESULTS

In total, 73 crowns had follow-up records which could be evaluated for this audit. Of these 73 crowns, 30 were placed by Clinician 1, and 43 were placed by Clinician 2. Table 4 shows the distribution of crowns according to tooth. Forty-five were replacement crowns and 28 were new crowns. The reasons for crown placement included secondary caries, lost or fractured existing crown, restoration of a root treated tooth, cracked tooth or replacement of a crown with poor margins.

Thirty-seven of the teeth were root treated prior to crown preparation. This included recent root treatments and long-standing root treatments. Thirty-six of the teeth had no previous root treatment. None of the teeth in the sample required subsequent endodontic treatment.

Sixty-two of the teeth had the impression recoded at the same visit as preparation.

One tooth fracture occurred during this audit period. The tooth in question (17) had been deemed restorable and was prepared for a zirconia crown with a vertical preparation. However the tooth had to be extracted as it fractured at cervical level, leaving the tooth unrestorable. This tooth was a maxillary second molar acting as a clasped abutment tooth for an upper partial cobalt-chrome denture. All other maxillary molars had previously been extracted due to deep caries.

One crown had to be remade as the buccal wall fractured during try-in at the fit appointment.

The mean follow-up time was 21 months with a standard deviation of 10 months and a range of 6-40 months *(Table 5)*.

Radiographic follow-up was available for 60 teeth. In most cases this was bite-wing radiographs, but a few cases had before and after peri-apical radiographs to compare. Radiographs were only taken when clinically necessary. The mean follow-up time for radiographs was 16 months with a standard deviation of 9 months. The range was 1-40 months. No change in alveolar bone level was noted when comparing these 60 teeth before and after placement of a crown with vertical margins.

Table 4. Distribution of crowns per tooth

Distribution of crowns	Number
Maxillary premolars	13
Maxillary molars	31
Mandibular premolars	5
Mandibular molars	24
Total	73

Table 5. Follow-up time (months)

	Follow-up time (months)				
Premolar or Molar	Mean	N	Std. Deviation	Median	Range
Premolar	21	18	11	16.5	6-39
Molar	20	55	9	19	6-40
Total	21	73	10	18	6-40

Of the 73 teeth in this audit, 69 had follow-up BPE scores. Periodontal pocket charting was recorded for teeth found to have pockets greater than 3.5mm.

Of these 69 teeth, 7 teeth (in 6 patients) had a periodontal pocket recorded either before or after treatment with the vertical preparation *(Table 6)*. Two of these teeth (crowns 3 and 4 from the table 6) were the same patient. One tooth showed an improvement from 6mm to 4mm, but the other showed a worsening from a 2mm to a 5mm pocket. This pocket is the only area where pocketing has increased around any of the 69 teeth for which records are available. Two of these teeth remained the same before and after crown placement, with 4mm pockets recorded on 1 surface. Four of these teeth showed an improvement. One tooth (mentioned above) had a pocket reduction from 6mm to 4mm. The 3 remaining teeth had pockets of 4-6mm before treatment but pockets no greater than 3.5mm after treatment. All 6 of these patients had stabilised periodontitis and undergo periodontal maintenance therapy with a hygienist 4 times a year.

The bleeding score was calculated for each tooth from records taken before and after vertical preparation for a crown. This comparison is represented in Figure 15 and the same data for the control teeth in Figure 16.

Of the 68 teeth with bleeding data available, 15 showed less BOP after treatment while 23 showed more BOP after treatment. 10 of the teeth showed no BOP before or after treatment while 5 of the teeth showed the same level of BOP before and after treatment.

Of the 68 teeth, 31 showed more bleeding on the crowned tooth than the control tooth, while 22 showed less. 8 teeth showed no BOP on either the crowned tooth or the control tooth. Seven teeth showed BOP at the same level both on the crowned tooth and the control tooth *(Table 7)*. The mean bleeding score for the crowned teeth (0.79) was higher than the mean bleeding score for the control teeth (0.62). A two-sample t-test (SPSS® Version 25) was used to test the null hypothesis that the means for the crowned teeth and the control teeth were equal, versus the alternative hypothesis that the means were not equal. The assumptions underlying the two-sample t-test were satisfied. The 68 crowned teeth (mean bleeding score 0.79 and standard deviation of 0.84) were compared with 68 control teeth (mean bleeding score 0.62 and standard deviation of 0.65). The 95% confidence interval for the difference in means (crowned teeth versus control teeth) was (-0.85,0.42). The hypothesis test did not show a significant result (p=0.19), so the null hypothesis was not rejected. In conclusion, the mean bleeding score for the crowned teeth and the control teeth are not different.

DISCUSSION

This audit found favourable results for teeth prepared with a vertical preparation for posterior zirconia crowns placed in general practice. The mean follow-up time was 21 months with a standard deviation of 10 months and a range of 6-40 months.

There was 1 failure requiring extraction of the tooth, in a patient with a high caries rate and a history of multiple extractions. The new crown had occlusal rests seats incorporated as part of the design, so it could also function as a denture abutment. The tooth was a lone-standing molar acting as a denture abutment. One year after crown and denture fit, the tooth fractured at cervical level. This tooth had a number of risk factors. Failure was not of the vertical preparation design in itself but failure of the underlying tooth. Further follow-up is needed to monitor the longevity of the other 72 teeth in this audit, and to analyse the modes of failure.

There was 1 failure requiring a re-fabrication of the crown. The buccal margin fractured during try-in. On this occasion, the thin-section zirconia was not strong enough to resist fracture.

No marginal caries was detected at crown margins, clinically or radiographically.

Table 6. Details on teeth with associated periodontal pocketing

Tooth number	Before crown preparation	After crown fit
1	4mm mesial pocket	8 pocket charts with no periodontal pockets on this tooth, followed by a recent pocket chart with a 4mm palatal pocket (no worse than before treatment)
2	4mm mesial pocket	4mm mesial pocket (same as before treatment)
3	6mm distal pocket	4mm distal pocket (improvement)
4	2mm distal pocket	5mm distal pocket (worse)
5	5mm mesial pocket	No pockets >3.5mm (improvement)
6	4mm lingual pocket	No pockets >3.5mm (improvement)
7	5-6mm pockets	No pockets >3.5mm (improvement)

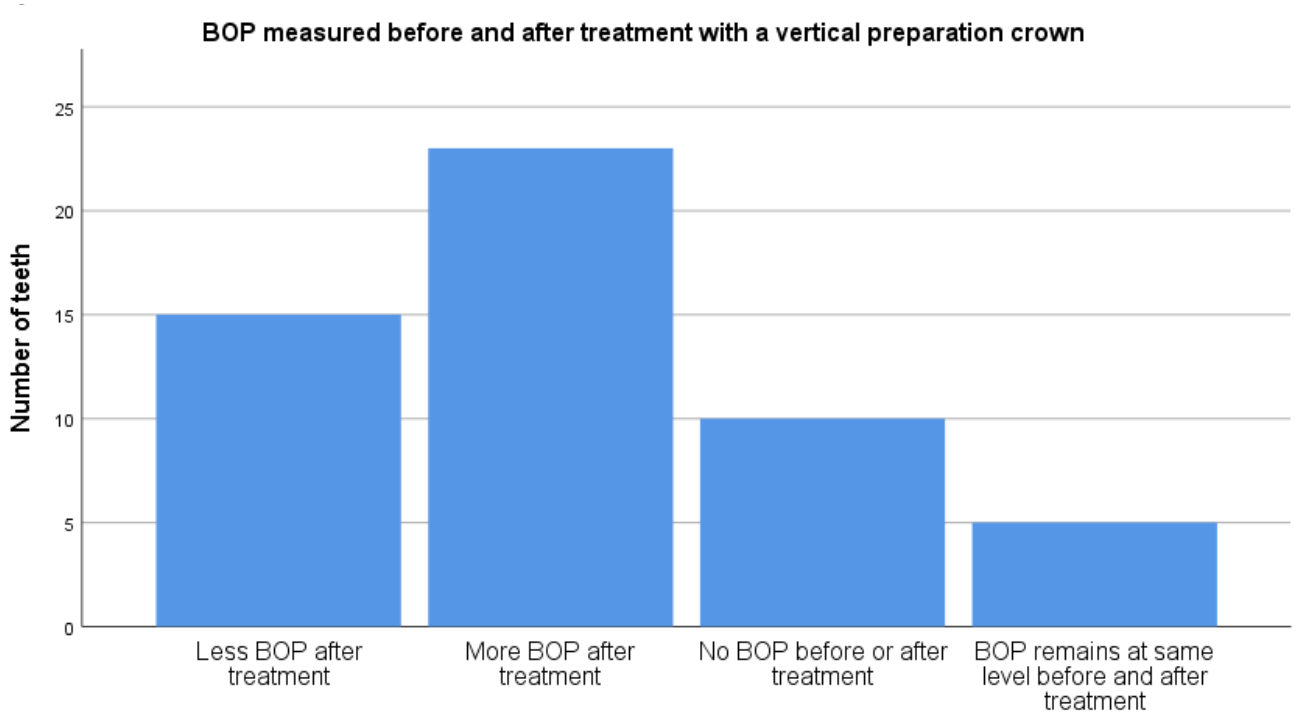

Figure 15: Graph showing comparison of BOP taken before and after treatment

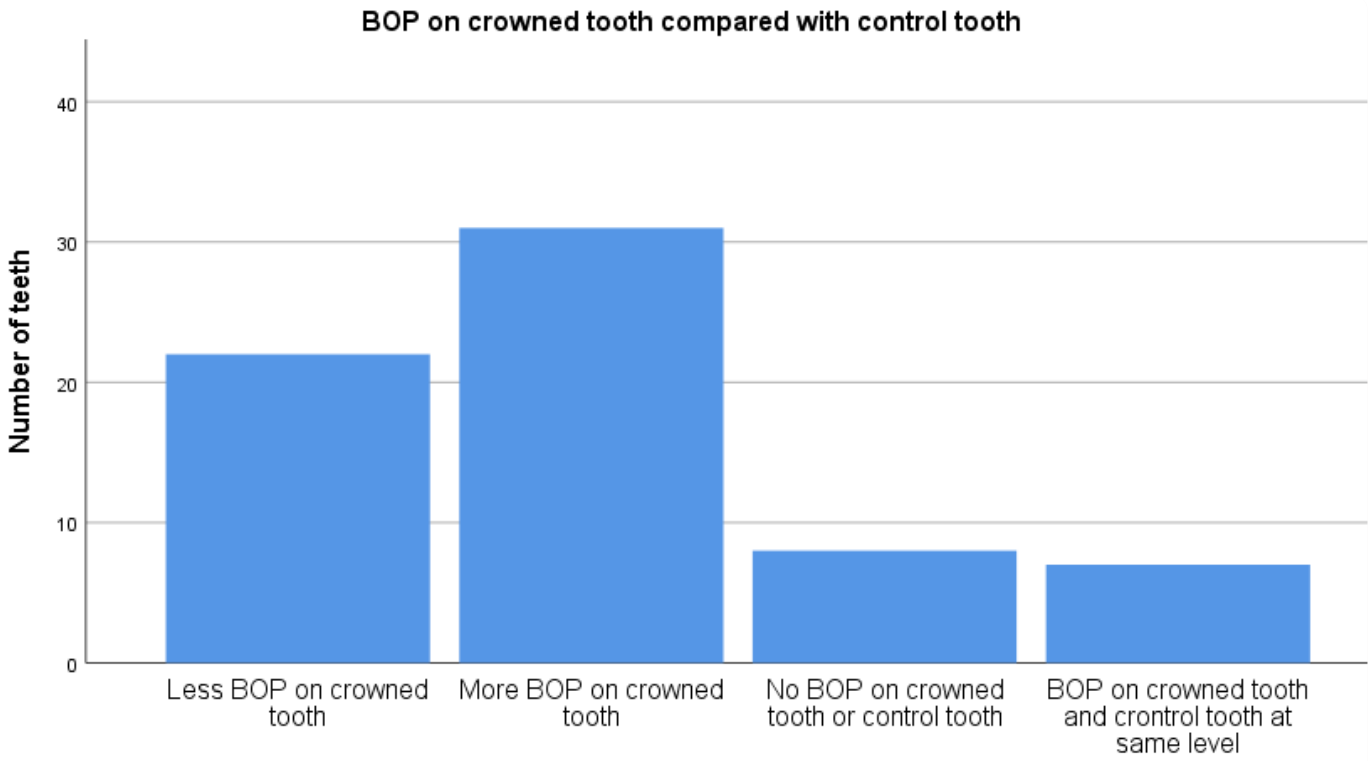

Figure 16: Graph showing a comparison of bleeding recorded on the crowned tooth and a control tooth

None of the teeth prepared with vertical preparations required subsequent endodontic treatment possibly due to the reduced depth of axial preparation required. It will be interesting to see longer term follow-up for this, and to compare this with the finding that 20% of vital teeth prepared for metal-ceramic crowns require endodontic treatment within 15 years.[15]

These recorded results compare favourably with the data published by Poggio *et al.*[16] on 102 knife-edge zirconia crowns and by Schmitt *et al.*[17] on 19 featheredge zirconia crowns.

Only one tooth showed an increase in periodontal pocketing around a crown. The patient had alveolar bone loss around these teeth from previous poor crown margins and localised

Table 7. Bleeding score comparing the crowned teeth with the control teeth

BOP (number of surfaces)		
	BOP crowned tooth	BOP control tooth
Mean	0.79	0.62
N	68	68
Std. Deviation	0.84	0.65
Median	0.5	0.5
Range	4	2

periodontal disease. Interestingly this patient had another crown in this audit where the pocket improved from 6mm to 4mm. However the pocket at the distal surface of an upper second molar, where the adjacent wisdom tooth had been extracted years before, showed an increase from 2mm to 5mm.

Several teeth showed an improvement in periodontal pocketing. No alveolar bone loss was seen on radiographic follow-up.

Bleeding data was compared before and after vertical preparation and knife-edge crown placement. 23 teeth showed more bleeding after crown placement while 15 showed less.

Bleeding data was compared for the crowned tooth and a control tooth which was usually a crown with a traditional margin. This allowed some comparison with horizontal margins although it is recognised that there are many other factors to take into account. The crowned teeth were found to have a higher mean bleeding score than the control teeth, but this difference was not significant. These results compare favourably with data published by Scutella *et al.*[14] on the periodontal assessment of 137 teeth with vertical preparations.

Several limitations to this retrospective audit need to be considered. Treatment was provided by two clinicians in one practice. The follow-up was recorded by one of these clinicians and a hygienist, as part of continuing care for these patients. There was no inter-examiner calibration between clinician and hygienist. All data was gathered as part of continuing care for patients and there was no set data gathered for this audit. As such, not all data is available for all crowns. The crowns were not placed simultaneously. The same type of margin was prepared for all crowns, but different CAD/CAM systems were used. Some crowns were monolithic zirconia, and some were zirconia veneered with ceramic, depending on the clinical circumstances. Only patients with follow-up data were included in the audit.

If the audit were to be run again, it would have been valuable to record the position of the crown margin at cementation and again at review visits. This would allow assessment of the role of gingival recession if present. It would also be better if the review appointments could be carried out by an independent clinician.

This practice-based clinical data reflects treatment carried out in general practice. The nature of general practice means that individual cases need customised treatment which can impact our ability to compare results. On the other hand, general practice data tests the procedure in a real-world clinical setting. Different zirconia systems were used and the time before impression recording varied depending on the clinical situation. Most impressions were recorded at the same appointment as the impression. This meant that soft tissue healing was predominantly taking place around the definitive crown.

Despite good results for knife-edge zirconia margins *in vitro*[17,18] manufacturers do not appear to recommend vertical preparations despite Beuer *et al.*[19] showing excellent fracture resistance which was superior to a chamfer margin. Beuer *et al.*[19] dismissed the vertical preparation only for periodontal reasons.

The data from this retrospective audit suggests that vertical preparations which provide a more minimally invasive preparation technique have similar outcomes to traditional preparations and therefore should be considered where a posterior crown is indicated.

CONCLUSIONS

With knife-edge margins now possible with zirconia, the vertical preparation is a credible option for crown placement or replacement. This enables greater conservation of natural tooth structure, compared to preparations with horizontal margin designs. Tissue handling and margin form are critical to success.

This audit has shown favourable outcomes for 72 posterior teeth prepared with a vertical preparation for knife-edge zirconia crowns.

The current evidence to support vertical preparations in periodontally healthy patients is weak. Further research is needed on the long-term effectiveness of knife edge zirconia margins and the periodontal outcomes of teeth prepared for vertical margins.

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